The impacts of occupant behaviour on energy performance, thermal comfort, indoor air quality, and health in social housing

Abstract: The UK's largely inefficient housing is a significant contributor to greenhouse gas emissions and a contributing factor to poor health outcomes of its residents. The social housing stock built between WWII and the 1980' is the same with a number of high-profile cases related to significant health impacts. It is largely accepted that user behaviour can have a significant contributory factor to these factors. Focusing on a single "flagship" sheltered housing block in East London the aim of this research is to understand and identify post-occupancy user behaviours that affect indoor air quality, thermal comfort, and energy usage, with the purpose of recommending retrofitting strategies. A questionnaire survey was conducted with the occupants to collect data on their behaviour patterns, preference and experiences related to energy use, ventilation and any associated health symptoms that they attributed to their living environment. Preliminary results show that to achieve thermal comfort and the healthiest environment residents must engage with behaviours that are both thermally inefficient and high energy consuming. Further analysis is required to make suitable recommendations, but these could include the installation of mechanical ventilation or providing low energy alternatives for acceptable IAQ. Any change to the building fabric must be accompanied by an education, reward, and support scheme to meaningfully change behaviour. By considering the user behaviour of occupants, retrofit measures can be more effective in reducing carbon emissions whilst also maintaining health environments for residents.

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1. Introduction

Social Housing in the UK is provided through a mixture of Local Authority and Housing Association owned stock, with the vast majority built between the end of WWII and the early 1980's (Shelter, 2023). Much of this housing stock (built before energy efficiency and long-term sustainability was central to housing policy and regulation and architectural ethos) is inefficient by modern standards with poor energy performance. In August 2007, the UK Government introduced Energy Performance Certificates (EPC) in England & Wales. An EPC informs you of how energy efficient a building is, how much it'll cost to heat & light the building, and what its carbon emissions may be. The EPC will give the property an overall rating from A (very efficient) to G (very in-efficient) (EnergySavingTrust, 2022). Only 40% of UK homes in England & Wales meet an EPC rating of A-C, (OpenPropertyGroup, 2023).

There is significant anecdotal and researched evidence that suggests a strong correlation between poor energy performance in residential homes and the ill health of the occupants (International Energy Agency , 2017). Respiratory conditions such as asthma and hay fever can be affected by poor internal air quality (IAQ) in homes and living in an energy inefficient environment can be detrimental to both the physical and mental health of occupants (Wouter Poortinga, 2018). The potential lethal effects of poor housing conditions have been brought to the public conscious recently due to the tragic death of Awaab Ishak, the 2-year-old who died from exposure to mold in his home (Weaver, 2022). The home was provided and managed by Rochdale Boroughwide Housing; a Housing Association who were found by the regulator to be negligible with a litany of failings in the case. They were found to have shown poor overall management and investigation of such issues and ultimately failed at providing a healthy and adequate accommodation for residents across their portfolio (Regulator of Social Housing, 2022).

In addition to the potentially serious impact on the health of its occupants, the energy efficiency of a home has significant ramifications for the environment and the climate crisis we are facing. Central to the UK Government achieving its net zero carbon target by 2050 is to improve the energy efficiency of buildings, with the built environment currently accounting for 25% of greenhouse gas emissions in the UK (UK Green Building Council, 2021; Karlsson, 2021). This highlights the importance of the operational efficiency of building in achieving the carbon reduction targets by 2050 as set out by the UK government (HM Government , 2021).

Whilst newer buildings are designed to embrace environmental sustainability and energy efficiency, existing housing stock is largely inefficient making up circa 48% of emissions of the total built environment (UK Green Building Council, 2021). With much of the social housing stock across both Local Authorities and Housing Associations built prior to modern regulations and policy on energy efficiency standards, comprehensive retrofitting strategies will be required to tackle the scale of the problem in the UK and achieve government targets.

The current cost of living, climate and energy crises increase the gravity and impact of energy inefficiency and its impact on people and environment. The impact of the covid-19 pandemic alongside record increases in temperature saw several days of extremely uncomfortable weather in thermally inefficient homes. The current socio-political situation in Europe has seen gas supplies reduce by 35% and a significant rise in energy costs. (BBC News, 2022). These circumstances have left millions of families facing rising food and energy costs, with some having to choose between 'Eating & Heating' (Viner, 2023).

The UK government does not have an agreed published retrofitting strategy, the ambitions to reduce the carbon output of the built environment are contained within the Net Zero Strategy and the Heating and Buildings strategy which focuses on the more immediate need for action to decarbonise heating sources for buildings in the UK setting out an action plan with schemes and policy focus for the 2020's (HM Government, 2021). Whilst there is not a centralized pot of funding focused purely on retrofitting of housing stock these ambitious targets and plans are underpinned by a few key accelerator programmes, such as the current Social Housing Decarbonisation fund, the Green Homes Grant, and the most recent Sustainable Warmth Competition.

Newham Councils planned retrofit for the Hamara Ghar sheltered housing scheme is partly funded as part of an award from the Social Housing Decarbonisation fund for homes with an EPC rating of below C. The aim of the fund is to support projects to; reduce carbon emissions; improve fuel poverty and improve the comfort, health and well-being of social housing tenants (HM Government , 2022) in addition to other ambitions. Within this wider national context, The London Councils Retrofit London Housing Action Plan was developed in response to the growing awareness of the urgent need to address the energy inefficiency of the city's housing stock if the targets as set out by the net zero strategy are to be met. A lack of coordinated national strategy and funding is highlighted with the funding and policy outlined above, described as narrow in its focus and not far reaching enough (London Councils , 2021). The action plan was developed by London Councils, an organization that represents the 32 boroughs and the City of London, in collaboration with a range of stakeholders including industry, government and community groups. Crucially as well as recognising the environmental impacts of our current housing stock. The plan highlights the need to address fuel poverty and improve the health and wellbeing of residents which is exacerbated by inefficient homes and the need for a "whole house approach" (London Councils , 2021).

In the context of occupant behaviour, the plan recognises that the behaviours can have a significant impact on energy use and emissions. To address this, the plan includes measures such as providing education and advice to occupants on how to reduce energy use, and offering incentives for behaviour change, such as lower utility bills for those who adopt energy-saving practices (London Councils , 2021). The plan also includes initiatives to improve the monitoring and feedback of energy use in homes, which can help occupants better understand their energy consumption and make informed decisions about how to reduce it. There is an understanding of the importance of engaging with occupants and promoting behaviour changes as key components of achieving its energy efficiency goals across the city's housing stock, with a focus on collaboration and innovation across the local authorities and with key stakeholders from the energy, environment, housing and construction sectors. Occupant behaviour is an essential component for any approach to retrofitting and decarbonisation both in terms of implementation and policy, though the specific needs of the end users as per demographic indicators are not always central to government objectives.

1.1 Health outcomes and living environment

The link between living conditions and health outcomes is well known and borne out by many years of research. In terms of Thermal Comfort (TC), there is a known link regarding TC and effects on occupants, in particular more vulnerable groups such as elderly, those with long term conditions such as Chronic Obstructive Pulmonary Disease (COPD), and children (Ormandy, 2012). Both overheating and thermally inefficient homes can have significant detrimental effects on health and can exacerbate or cause long term conditions with both factors being equally important when addressing retrofitting strategy.

The World Health Organisation (WHO) study "Housing, Energy and Thermal Comfort: A review of 10 countries within the WHO European Region" provides an overview of the state of housing and its impact on energy consumption and thermal comfort. The report highlights the prevalence of poor-quality housing and inadequate heating, which can lead to health problems and increased energy consumption (World Health Organisation Regional Office for Europe , 2007). It also examines the factors that contribute to poor thermal comfort, such as inadequate insulation and ventilation. Overall, the report emphasizes the importance of thermal comfort when working towards sustainable and energy-efficient housing to improve living conditions and reduce carbon emissions. Particularly prevalent to the user cohort and project that this study is focused on, is the strategic approach of placing thermal discomfort at the center of retrofit strategy when considering the needs of occupants in fuel poverty. In cases where the thermal comfort and economic conditions of the occupants have not been considered then building retrofitting does not always achieve the expected energy savings and carbon reduction targets (Vilches, 2017). Occupant's thermal comfort as a self reporting measure is of particular importance when addressing retrofitting strategies. This is most relevant for those who are facing fuel poverty.

Another well researched area regarding occupant impact is the connection between Indoor Air Quality (IAQ) and health outcomes. With over 4 million deaths per year linked to it, poor indoor air quality can cause a range of health problems including respiratory problems, allergies, asthma, and even more serious illnesses such as lung cancer (Raju S, 2020). IAQ can be affected by a variety of factors, including ventilation, humidity, temperature, and the presence of pollutants such as chemicals, dust, and mould (Tran, 2020). These factors can all have an impact on the quality of the air that we breathe indoors and can lead to a range of health problems. There have been numerous studies investigating this link with the connection between occupant behaviour and indoor air quality long established.

The "Sick Building Syndrome" study conducted by the World Health Organization (WHO) in the 1980's was a landmark study that investigated the relationship between indoor air quality and the health of occupants. The study aimed to identify the causes of the symptoms that were reported by occupants of certain buildings, which included headaches, fatigue, and respiratory issues (World Health Organisation , 1984). The study found that poor indoor air quality was a major contributor to these symptoms, leading to what became known as "sick building syndrome." The study highlighted several factors that could contribute, including inadequate ventilation, contamination from outdoor pollutants, and indoor sources such as carpets and furnishings. The study identified the importance of occupant behaviours, such as smoking, the use of cleaning chemicals, cooking and not ensuring adequate ventilation. (Health and Safety Executive , 1993).

The converse relationship between indoor air quality and energy efficiency solutions has also been explored with standards for energy efficiency reducing a lack of natural ventilation and subsequently the indoor air quality. (Liva Asere, 2018) This in turn requires mechanical ventilation which increases energy consumption with the net gain or loss an important factor to be considered in any retrofit plans. In addition, any occupant behaviour that contributed to poor indoor air quality as described would be exacerbated by poor natural ventilation.

1.2 Energy Performance and occupant behaviour

The Energy Performance of Buildings Directive is a European Union directive aimed at the reduction of carbon produced by buildings. Core to the delivery of the directive is the requirement for the energy performance of all buildings to be measured and recorded via an Energy Performance Certificate EPC, which in the UK gives buildings a rating of A the most efficient to G the least efficient. EPC certificates consider the fabric, heating systems, age, insulation and particular fittings such as showers to give the associated efficiency rating for the property (Y. Li, 2019) but do not evaluate user behaviour. Energy performance of buildings is acutely affected by occupant behaviour with a number of studies indicating a significant difference between predicted building performance and measured output (Far, 2022) as much as 300% in some cases (Delzendeh, 2017).

Despite the strong correlation between poor performance, occupant usage and subsequent negative health outcomes, many retrofit strategies do not consider this behaviour due to the variance in behaviour and potential scenarios that could affect performance through usage. Occupant behaviour is core and should be measured via a variety of techniques, ranging from self- reported findings to measuring temperature and moisture of the air within the dwelling (Santamouris, 2005).

Energy consumption, according to The International Energy Agency (IEA) is determined by 6 factors: 1) Climate; 2) Building envelope characteristics; 3) Building services and energy systems characteristics; 4) Building operation and maintenance; 5) Indoor environmental quality provided; and 6) Occupant activities & behaviour (Bruna Faitão Balvedi, 2018).

"Energy related Occupant behaviour… (is defined as) …observable actions or reactions of a person in response to external or internal stimuli, or actions and reactions of a person to adapt to ambient environmental conditions" (Bruna Faitão Balvedi, 2018). Occupants' decisions and behaviour depend on both deterministic and random responses to stimuli and are thus stochastic in nature; the same occupant can respond differently, on different occasions and even in response to identical stimuli (Jessen Page, 2007). For example, a home without insulation in the winter months will be far colder indoors than a home with insulation. The occupant residing in said building without insulation would most likely utilize a heater to stay warm inside depending on their individual thermal comfort. Using a heater would increase the energy consumption which will increase the energy bill for the occupant. Alternatively, the occupant could wear additional layers of clothes to combat the indoor temperature instead of using a heater. (Yan, 2015) This decision would not increase the energy consumption and the occupant would not have increased their energy bill.

Because of the complex nature and variance of occupant behaviours a mixture of both users reported finding and technology led monitoring should be utilized to best understand this variance and give accuracy. Stochastic models should account for a variety of behaviours, variation over time, and variation between individuals so that we can achieve more robust renovation and design solutions, better load profiles for sizing and control of energy conversion systems and supply networks and for better energy use and comfort predictions (Juan Mahecha Zambrano, 2021).

2. Methodology

A mixed method including critical literature review and questionnaire surveys were used to understand specific elements of user behaviour and the impact of this on the living environment and health of the occupants. This is within the context of a population of older residents and an older and assumed more environmentally inefficient building. The questionnaire was designed to guide the user to give specific answers that can be compared and analyzed to understand trends against behaviour, rather than subjective user experience.

The first section of the questionnaire focuses on specific elements of occupant behaviour, that could have effects on the indoor air quality of the residence, the heat retention and or loss as well as moisture levels including frequency of opening windows, cooking, washing, clothes washing and drying; utilization of heating and mechanical ventilation and their primary reasons for this. The second section of the questionnaire focuses on any environmental issues internally and externally, such as damp, mold, water leaks and any surrounding pollution. The third section of the questionnaire asks residents about any long-term conditions such as asthma and hay fever, behaviours including smoking and pet ownership as well as any symptoms they suffer from with their associated frequency that could be because of their living environment and IAQ. The symptoms surveyed have been chosen due to their link with poor IAQ. The final questions focus on demographics, occupancy numbers and provide an opportunity for any additional information. All collected user feedback has been fully anonymised with results based on data trends.

Within the earlier stated context of the demographic profile of the residents it was required to work directly with responses allowing them to share their experiences whilst giving quantifiable data points. The study focuses on a total of 26 properties (22% of total households) within the building with the majority being single occupancy and non-working age adults. Whilst the relatively small sample size means that caution has been exercised in drawing conclusions the demographic similarity of the residents has allowed for any results that deviate to be reviewed and analyzed for correlation and patterns to offer suggested reasons as to the potential impact of human behaviour of the reported outcomes. Statistical analysis has been used with a focus on participant demographics, participant behaviour, participant health, participant behaviour in context of reported issues with the building and assessment of reported health symptoms in context of long-term conditions and participant behaviour. There were some void answers throughout the survey i.e., left blank with percentages based on the number of complete answers.

The chosen resident block for this study is an over 50’s only retirement home and sheltered housing unit (Figure 1). The block allows for mixed family households though is aimed at more elderly residents. Of our respondents none were households with any occupants under 18. Excluding void responses 75% of our respondents lived in single occupancy households with 22% of them currently under occupying i.e., living in 2/3-bedroom properties. 62.5% of respondents were female, 37.5% male. Residency length ranges from 6 months to 29 Years with a median of 10 years. Each resident unit operates on two electric meters with the local authority providing free electricity in the evenings. Though this was not a question asked within the questionnaire survey this was anecdotally feedback via the engagement with residents with feedback that whilst they either do or are encouraged to keep their heating on at night to take advantage of this it often leads to overheating and need to open windows.

Figure 1. Case study Building.

3. Results

3.1 External ventilation

Participants were asked about frequency of window opening across the 4 main living areas; living room; bedroom; bathroom and kitchen during winter and summer to see if behaviour changed depending on season (Figure 2). 65% of respondents opened their bedroom and living room windows at least once a day even in winter suggesting that this is where the most time is spent. 80% of them open their windows less than once a day with 50% not opening their windows at all in their kitchen in winter and 88% never opening their bathroom windows in winter.
As expected, participants' use of windows for natural ventilation increases significantly in summer with bedroom and living room windows opened at least once a day by 96% of residents. Similarly, this increased for both kitchen and bathroom windows though not as significantly with 42% of respondents opening their kitchen windows 2-3 times per week and 62.5% of residents still not opening their bathroom window at all even during summer. The primary reason for opening windows across all room categories in winter and summer seasons was to "provide fresh air". This ranged from 86% to 80% across the bedroom and kitchen which were the primary rooms where windows were opened regularly.

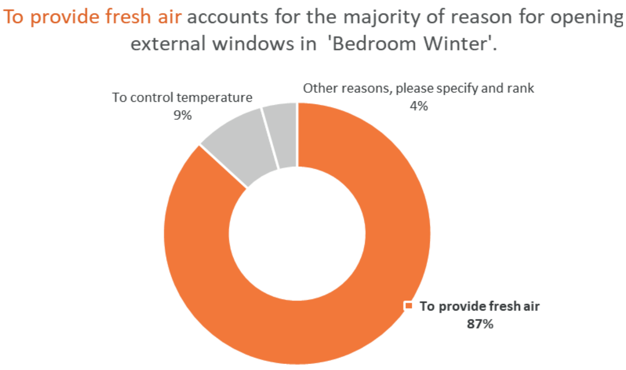

Figure 2. Operative temperature in (top) Living room (bottom) bedroom during May-September

3.2 Cooking, Washing and Heating

As confirmed in a study by Vardoulakis et al. (2020), "Household characteristics and occupant activities play a large role in indoor exposure" to air pollutants. As well as affecting IAQ, these activities are known to play a significant role in the thermal regulation and carbon pollution caused by a building and so an understanding of these behaviours is key to any retrofitting strategies. As per figure 3 and 4, 35% of residents wash and cook once a day with the associated indoor air pollutants and heat creation from this. This is against the reported natural ventilation that only 22% of respondents open their bathroom windows in winter and 50% open their kitchen windows. In terms of mechanical ventilation this increases to 58% using extractor fans in their kitchen at least 2-3 times per week with 33% still not using any mechanical ventilation. In the bathroom where 88% of respondents do not open their windows at all in winter 62% use mechanical ventilation at least once a day with 37.5% not using any mechanical ventilation. Despite this only 15% residents have reported any damp or mold in their bathroom. Of this 75% do not use any mechanical or natural ventilation at all, which given known causes for damp and mold in property is likely to be connected. The building has communal washing and drying facilities with 62% of residents from our
sample using this as their primary facility to wash and dry clothes. Clothes drying is known to increase moisture within the room environment however of the 31% that use an airer within the property there is only once case of damp or mold reported with the resident not opening their windows in the winter or using mechanical ventilation (they do regularly open external windows in the summer months).

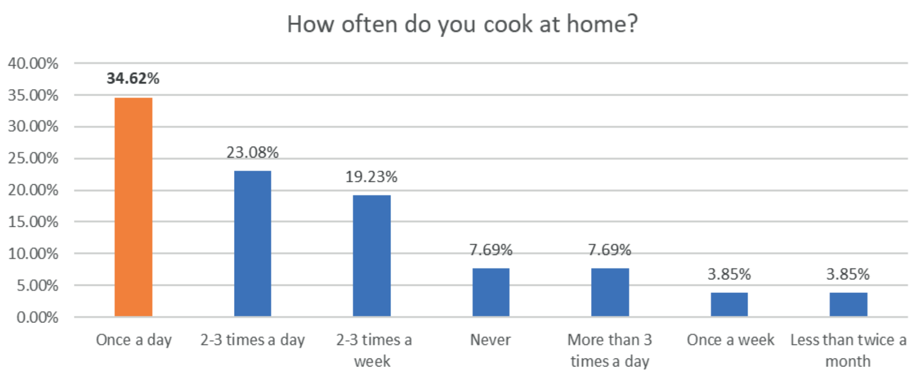

Figure 3. Cooking Frequency.

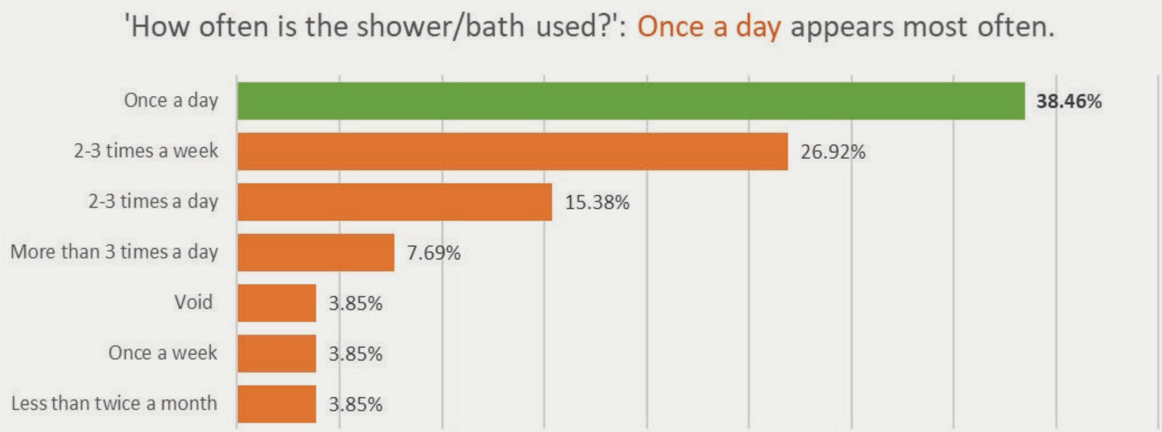

Figure 4. Bathing/Showering Frequency.

3.3 Health Conditions and symptoms

Smoking is known to have a particularly negative affect on IAQ and health both through direct and passive intake of inhalants. Only 3.89% of residents are smokers as per the survey with no reported respiratory or other health symptoms as well as regular external ventilation practices associated. With such a small, reported sample of smokers any conclusions cannot be drawn as to impact on IAQ.

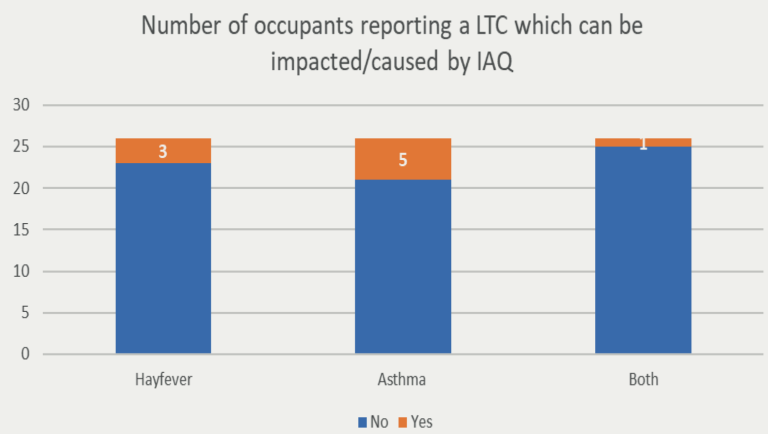

Figure 5. Occupants reporting having Asthma and Hay fever.

As noted above the survey asked respondents about their long-term conditions and any related or unrelated health symptoms focusing on both conditions and symptoms linked to IAQ and occupant behaviour. As per fig 6, 5% of occupants have asthma, 3% hay fever and 1% suffer from both. Of those with Asthma 40% reported damp or mould in their property and account for 50% of total reported cases of damp and moulds from all respondents. Despite the low reported prevalence of known issues within the properties i.e., damp and mould and the low rate of residents suffering from either hay fever or asthma there were significant reported health symptoms, itchy or watery eyes at 56%, headache at 52% and lethargy or tiredness at 44% (see Figure 5).

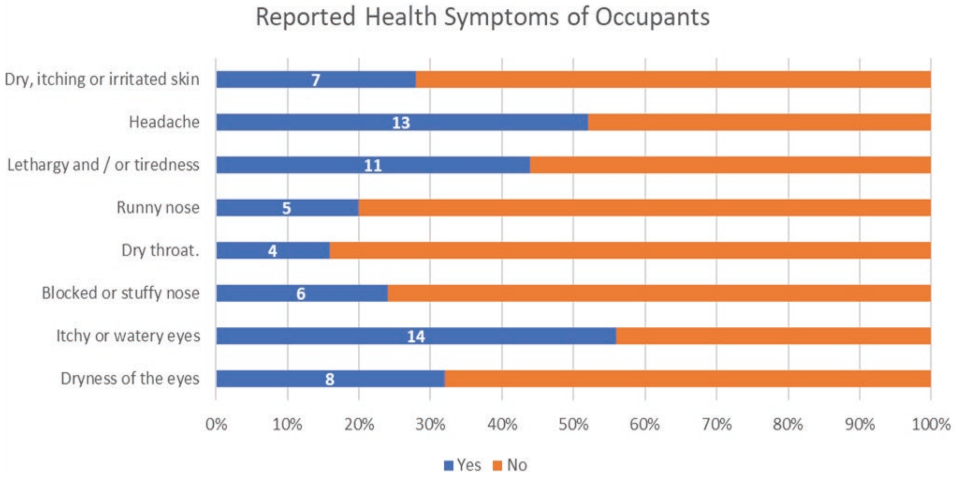

Figure 6. Reported health symptoms suffered by occupants.

At 56% itchy or watery eyes is the most prevalent health symptom despite only 14% of those reporting this have hay fever (Figure 6). Looking at other potential irritants 64% of this cohort cook at least "once a day" with 42% cooking from "2-3+ times a day". Looking at just this subset of 64% of those with itchy or watery eyes 55% never open their windows during winter and all spend 18-24 hours a day inside the property. Though this is for the winter months, it is possible that this constant exposure to indoor pollutants is a cause for the reported symptom. Similarly, looking at the 56% who report headaches, 76% cook at least once a day and 60% of them do not open their kitchen windows in winter. Again, all spend 18-24 hours a day in their homes. Though a direct cause and effect cannot be drawn due to other potential lifestyle factors a statistically significant correlation can be seen within our sample size. Whilst 44% of residents report lethargy or tiredness, no statistical significance is prevalent though it could be proposed that the age of the respondents is a potential factor.

4. Conclusions

This study examining occupant behaviour via the survey questionnaire has revealed some interesting correlations between external ventilation and poor health outcomes. The study aimed to investigate the relationship between occupant behaviour in relation to daily living habits, use of external and mechanical ventilation, heating use and health outcomes among occupants in an over 50's retirement sheltered housing building. The findings of the study indicated some correlations between the rate of ventilation and health. The analysis suggested that inadequate ventilation coupled with regular cooking was associated with an increased risk of symptoms associated with IAQ particularly itchy and watery eyes and headaches. These findings align with existing literature, emphasizing the importance of proper ventilation for maintaining acceptable indoor air quality and occupant well-being. A more expansive assessment of all residents in the building with follow up interviews about behaviour and health outcomes should be considered to enhance the findings as well as a direct comparison of data measuring devices (IAQ data loggers) against each respondents' responses as well as a refinement of questions asked. Retrofitting strategies could be considered to address the insufficient ventilation reported especially during the winter months and in key areas of heat, moisture and pollutant creation such as the kitchen and the bathroom. The suggested retrofit strategies must be assessed in context of wider factors such as budget and impact of interventions on residents, thermal comfort and energy performances.

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